# OPTIMIZATION OF MICROMILLINGPROCESS USING GREY TAGUCHI METHOD

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

**Bachelor of Technology**
**In**
**Mechanical Engineering**

By

**MAYANK JOSHI**
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**Department of Mechanical Engineering**
**National Institute of Technology**
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Under the Guidance of
**Prof K. P. MAITY**

**Department of Mechanical Engineering**
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**Rourkela**

# CERTIFICATE

This is to certify that this thesis entitled, "**OPTIMIZATION OF MICROMILLING PROCESS USING GREY TAGUCHI METHOD"** submitted by Mr. **MAYANK JOSHI** in partial fulfillments for the requirements for the award of Bachelor of Technology Degree in Mechanical Engineering at National Institute of Technology, Rourkela is an authentic work carried out by him under my guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

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# ABSTRACT:

Recently the need of micro technologies are growing rapidly. Demand of microscale miniaturized parts are increasing in industries like electronics, aerospace, optics, telecommunication, medical, automobile etc. where quality is the most significant element. Micro-machining, micro-molds and micro-system are modern engineering science for mass production of the 3D micro-components with an accuracy of microns in a wide range of workpiece material. Mechanical micromachining is an important method in micro-machining process which includes micro-drilling, micro turning and the most efficient micro-milling. IN this project we will perform a micro milling process on Inconel aerospace alloy workpiece using a High Speed Steel tool of 1mm diameter on the CNC machine available in our workshop. Our main objective is to determine the optimal value of the process parameter commonly used in the micro milling process which are Feed Rate, Spindle Speed and Depth of cut so as to reduce the output parameter such as cutting force, cutting time and cutting torque.

# TABLE CONTENT:

# FIGURE CONTENT:

# INTRODUCTION:

Recently the need of micro technologies are growing rapidly. Demand of microscale miniaturized parts are increasing in industries like electronics, aerospace, optics, telecommunication, medical, automobile etc. where quality is the most significant element. Micro-machining, micro-molds and micro-system are modern engineering science for mass production of the 3D micro-components with an accuracy of microns in a wide range of workpiece material. Mechanical micromachining is an important method in micro-machining process which includes micro-drilling, micro turning and the most efficient micro-milling. Micromachining is a diminish edition of conventional machining process, but the ratio of feed per tooth to tool radius is considerably higher compared with conventional end milling [1] and large part of the heat generated is channeled out to the surrounding through the chips generated during machining hence low cutting force needed, temperature of the workpiece became low and provides less straining in workpiece[5].One major vantage of micromachining is it can machine parts of different shape and size with a large range of workpiece material. Material removal rate of milling is greater than any other material removal process available in our industries. Also its surface finish is good. Material removal rates increases by increasing the feed rate and spindle speed and decreasing the depth of cut[5]. Now a days computer numerically controlled (CNC) machine tools are used widely because it enhances the surface quality of the workpiece, allow automated machining and enhances the productivity of the lineman and the machining process [1]. Chip generation in micro-milling is very different from that of conventional milling because of high negative rack angle. Very small tool run-out also affects the process[1]. Feed rate, spindle speed, tool diameter, depth of cut, material of the workpiece, etc. are the major parameter which affects the cutting force, torque, surface roughness, cutting time and tool wear[1]. Here we are considering the output variable as cutting force, cutting time and torque required by varying feed rate, spindle speed and depth of cut. Through the knowledge of cutting force we can find out the productivity, the power consumption of the cutting process and tool wear which is quite difficult to know in case of micro machining because of its small tool size[1].

# CHAPTER-1

# LITRETURE SURVEY:

EmelKuram, Babur Ozcelik[1] investigated on micro milling of AL 7075 with a vicker hardness of 139 using Taguchi based Grey Relational optimization method by taking spindle speed, feed per tooth and depth as process parameter and the response variables were tool wear, force and surface roughness. They used 800 micro meter diameter ball end mill tool. SEM results shows the accumulation of plastically deformed work piece. They found the optimized value to minimize: (A) ***tool wear*** were depth of cut of 50 µm, feed per tooth of 0.5 µm/tooth and spindle speed of 10,000 rpm. (B) ***Fx*** were spindle speed of 10,000 rpm, feed per tooth of 0.5 µm/tooth and depth of cut of 100 µm. (C) ***Fy*** were spindle speed of 10,000 rpm, feed per tooth of 0.5 µm/tooth and depth of cut of 75 µm. (D) ***Ra*** spindle speed of 12,000 rpm, feed per tooth of 0.5 µm/tooth and depth of cut of 50 µm. They used Multi-objective optimization method to find out the optimized values for minimizing the tool wear, Fx, Fy and surface roughness, were spindle speed of 10,000 rpm, feed per tooth of 0.5 µm/tooth and depth of cut of 50 µm.

Mao-yongLIN , Chung-chen TSAO[2], investigated The micro milling electrical discharge machining (EDM) process of Inconel 718 alloy using tungsten carbide tool electrode of diameter of 200 µm by taking peak current, pulse on-time, pulse off-time and spark gap as process parameter while the response variables are as such: Electrode wear (EW), material removal rate(MRR) and working gap(WG) by the Grey-Taguchi method. They found the optimized value to (A) minimize EW were peak current 0.5 A, pulse on-time 6 µs, pulse off-time 25 µs and spark gap 60 V. (B) higher MRR were peak current 1.5 A, pulse on-time 1 µs, pulse off-time 3 µs and spark gap 45 V (C) lower working gap were peak current 0.5 A, pulse on-time 1 µs, pulse off-time 25 µs and spark gap 60 V. (D) obtain good multiple performance characteristics in micro milling EDM of Inconel 718 were 0.5 A peak current, 3 µs pulse on-time, 3 µs pulse off-time and 60 V spark gap. They concluded that we can achieve low EW by increasing pulse off-time and spark gap, and decreasing peak current. Under the optimal obtained parameters the electrode wear decreases from $5.6\times10^{-9}$ to

5.2×10−9 mm3/min, the material removal rate increases from 0.47×10−8 to 1.68×10−8 mm3/min, and the working gap decreases from 1.27 to 1.19 μm.

W. Wang, S.H. Kweon[3], they considering spindle speed, feed rate, depth of cut and tool diameter as the micro-end-milling cutting parameters to investigate the surface roughness of Brass by applying ANOVA and RSM statistical methods. They built A new surface roughness models by Full factorial design using the MBC toolbox and found that increasing the structure and tool stiffness and decreasing the spindle chatter or vibration is the optimized step for low surface roughness of the workpiece, stiffness is the most important factors in micro-end-milling whereas feed rate played an important role when other parameters are constant.

S Datta, B C Routarab, Asish and S SMahapatra[4], they investigated a multi-objective optimization problem CNC end milling of 6061-T4 Aluminum by applying Principal Component Analysis (PCA) coupled with grey based Taguchi method (L25 Orthogonal Array) for predicting optimal setting. Depth of cut, spindle speed and feed rate were taken as process parameters and the performance characteristics were center line average roughness (*Ra*); root mean square roughness (*Rq*); and mean line peak spacing *(Rsm*).

H.S. Lu, C.K. Chang, N.C. Hwang, C.T. Chung[5], they investigated the Grey relational analysis coupled with principal component analysis for optimization design of the machining parameters for rough cutting processes in high-speed end milling of SKD61 tool steel(hardness 40HRC) with the cutting tools made of tungsten carbide and coated with TiAlN. The optimized set of machining parameters obtained were milling type- downmilling, spindle speed of 12000 rpm, feed rate of 0.04 mm/t, axial depth of cut of 0.8 mm, and radial depth of cut of 1.0 mm with the respective performance characteristics of Tool life:100 min, Metal removal rate: 25.6 mm3/s.The corresponding confirmation tests shows that tool life, metal removal rate, and total removal volumes increase by 26.31%, 27%, and 60.39%, respectively.

ANISH NAIR1 & P GOVINDAN[6], they highlights the Taguchi method (*L*25 Orthogonal Array) using Grey relational analysis coupled with principal component analysis for optimization design of the machining parameters for CNC END MILLING of medium leaded brass UNS C34000 with the CVD coated carbide cutting tool. The optimized set of machining parameters obtained were Depth of cut= 0.25mm, Spindle Speed = 2100 rpm, Feed rate = 550mm/min and the performance characteristics were center line average roughness *(Ra)*; root mean square roughness *(Rq )*; kurtosis *(Rku)* and mean line peak spacing *(Rsm)*.

S Moshat, S Datta, B Asish and P Ku Pal[7]**,** They investigated the new entropy measurement technique to calculate individual response weights combined with grey-Taguchi method(L9Orthogonal Array) to optimize process parameters spindle speed (S), feed rate (*f*) and depth of cut (*d*) of CNC end milling process in order to achieve good surface roughness (Ra value) and high material removal rate (MRR).

Vijay Kumar Meena1 and Man Singh Azad[8],as machining of Ti-6Al-4V(ASTM Grade 5) is difficult by conventional machining techniques, they investigated micro-electric discharge machining (micro-EDM) of Ti-6Al-V(ASTM Grade 5) alloy with tungsten carbide electrode which is easy to machine as compared to the conventional one, by performing Grey relational analysis and Taguchi method(L18Orthogonal Array) to optimize the machining parameters:voltage, frequency, and width in order to achieve good metal removal rate (MRR), low overcut (OC) and low tool wear rate (TWR). Voltage has been found to be the most important machining parameter for output performance characteristics. Further, the optimized values of machining parameters were found out to be: voltage (80V), frequency (150 Hz), pulse width(2 μs) and current(50).

Chorng-JyhTzenga, Yu-Hsin Lin, Yung-Kuang Yang, Ming-Chang Jeng[9],They investigated CNC turning operation for SKD11 (JIS) using Taguchi method (L9 orthogonal array) coupled with Grey relational analysis. They took speed (m/min), the feed rate (mm/rev), the depth of cut (mm), and the cutting fluid mixture ratios (%) as the process parameters with three levels for each parameter where as roughness average (Ra (μm)), roughness maximum (Rt (μm)), and roundness (μm) were taken as response variable. They found the Optimized input variable to be cutting speed of 155 m/min, a feed rate of 0.12mm/rev, a depth of cut of 0.8mm, and cutting fluid ratio of 12% is the optimal parameter combination of the turning operations giving the optimized response variable as the roughness average of 1.0280μm, the roughness maximum of 4.5302 μm, and the roundness of 0.74µm. The depth of cut was identified to be the most influential factor on the roughness average and the cutting speed is the most influential factor on the roughness maximum and the roundness. The significant sequential order for the controllable factors to:

a) The roughness average: the depth of cut, the cutting speed, the feed rate, and the cutting fluid mixture ratios.
b) The roughness maximum: the cutting speed, the depth of cutting, the feed rate, and the cutting fluid mixture ratios.
c) The roundness: the cutting speed, the depth of cutting, the feed rate, and the cutting fluid mixture ratios.

# CHAPTER-2

# EXPERIMENTAL SETUP:

## 2.1 EXPERIMENTAL SET UP:

In this experiment, 2mm thick INCONEL sheet was taken as a work-piece, with dimension of-length X breadth (80 mm X 30 mm). The milling cutter which is used in the experiment is High Speed Steel milling cutter with a dimension of 1mm diameter. The workpiece is mounted on the dynamometer with the help of nut and bolt. Dynamometer is mounted on the saddle of the CNC machine. Dynamometer is connected with the amplifier which shows the force component and torque in the digital screen. The micro-milling experiment is conducted in the central workshop of NIT Rourkela, India.

9272A type 4 component dynamometer measures:- force and torque.

Stop watch measured: - time.

## 2.2 SOME SPECIFICATION:

### 2.2.1 MILLING CUTTER:

Type--------------------- High Speed Steel milling cutter

Diameter---------------- 1mm

### 2.2.2 WORK-PIECE:

| | |
|---|---|
| Type | : INCONEL (AEROSPACE MATERIAL) |
| Density | : 8.19 g/cm3 |
| Composition | : Ni 72 |
| | : Cr14-17 |
| | : Fe6-10 |
| | : Mn 1 |
| | : Cu0.5 |
| | : Si 0.5 |
| | : C 0.15 |
| | : S 0.015 |

## 2.2.3 AMPLIFIER:

Type----------------------- 5070A

Company ---------------- Kistler Corporation

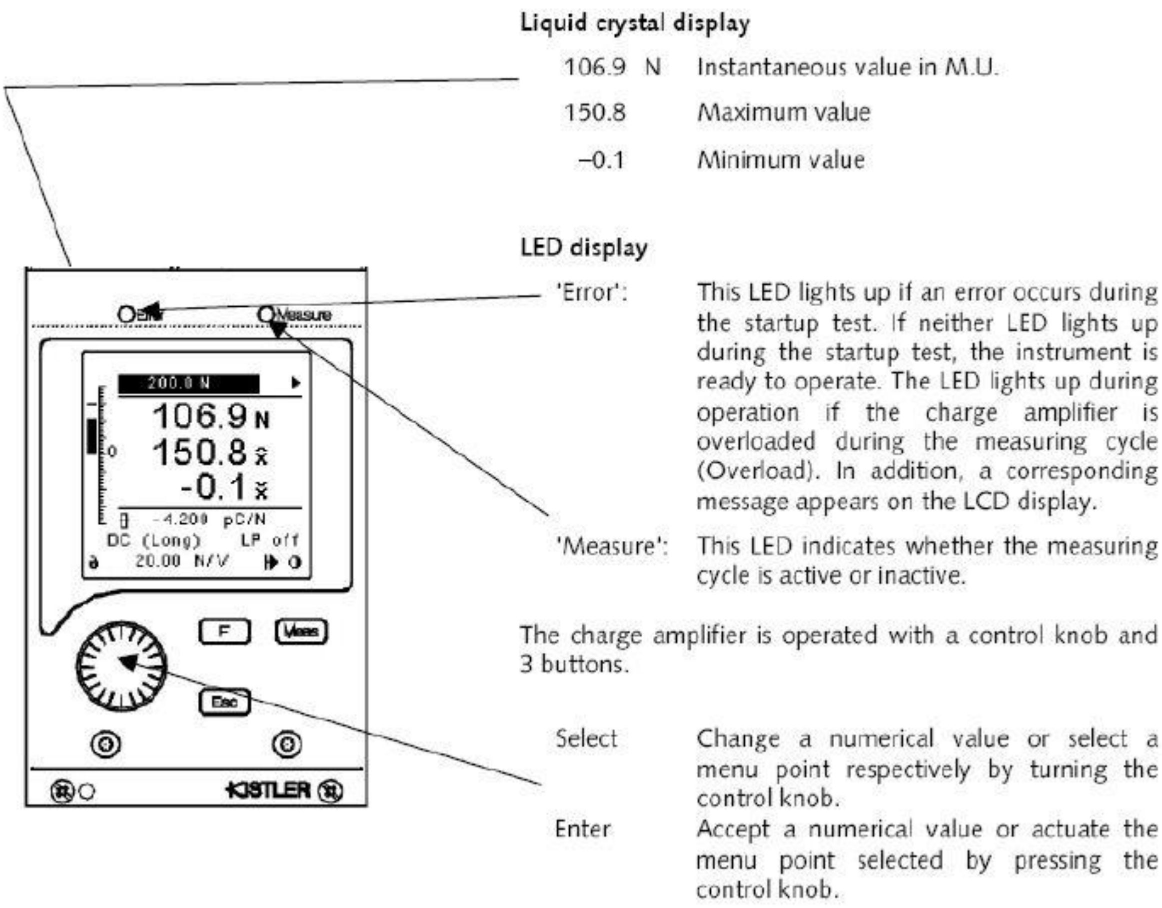


**Figure No. 1: Display of charged amplifier**

## 2.3 CNCSPECIFICATION:

| | |
|---|---|
| Company name | : Ralliwolf Limited, Bombay (400080) |
| Type | : WDH |
| Serial No | : B913238 |
| Power rating | : 415V, 3ϕ, 15KVA |
| Axes motor | : Fanuc Servo motor β 4i series |
| Spindle motor | : Fanuc spindle motor β 3i series |
| F/L amps | : 2.55A |
| N/L RPM | : 560 rpm |
| AC/DC volts | : 235V |

## 2.4 CNC PROGRAM:

```
G28 G91 Z0;
G00 G40 G80 G90 G54 X0 Y0;
M03 S2000;
G00 Z2;
# =0.045;
N1 G01 Z-#1 F2;
#1 +#1+0.045;
G01 G04 X25 Y0 F15;
G01 G40 X0 Y0;
IF [#1 LT 0.09] THEN GOTO1;
G00 Z5;
G28 G91 Z0;
G28 G91 Y0;
M30;
```

## 2.5 DYNAMOMETER:

The Kistler Dynamometer 9272 A with Charge Amplifier 5070 A measures the three perpendicular components of the force (Fx,Fy,Fz) acting on the workpiece as well as the moment. The dynamometer has high rigidity and hence high natural frequency. The high resolution enables very small dynamic changes to be measured in large forces. The dynamometer measures the active cutting force regardless of its application point. Both the average value of the force and the dynamic force increase may be measured. The usual frequency range depends mainly on the resonance frequency of the entire measuring rig [17].

The passive force is denoted as Fc (Fz),the feed force as Fs (Fx) and the normal feed force as Ft (Fy). The dynamometer is mounted on the saddle of the CNC. These three component of the cutting forces are displayed by the charged amplifier.

| | |
|---|---|
| Type | : 9272A |
| Company | : Kistler Corporation |


**Figure No. 2: Tool dynamometer**

## Table No. 1: DYNAMOMETER SPECIFICATION[18]:-

| **Specifications** | **Unit of measures Metric \| Imperial** | **Type 9272** |
|---|---|---|
| Measuring range (Fx) | kN | -5.00 ... 5.00 |
| Measuring range (Fy) | kN | -5.00 ... 5.00 |
| Measuring range (Fz) | kN | -5.00 ... 20.00 |
| Measuring range (Mz) | kN·m | -0.200 ... 0.200 |
| Design | | Force Plate / Dynamometer |
| Number of axes | | 4 |
| Measuring mode | | Direct |
| Operating temperature range | °C | 0 ... 70 |
| Height | mm | 70.0 |
| Outside diameter | mm | 100.0 |
| Inside diameter | mm | 15.0 |
| Degree of protection | IP | 67 |
| Cable is replaceable | | Yes |
| Connector / cable | | Plug |

# CHAPTER-3

# PROCEDURE

Firstly, the work-piece was cut according to above mentioned dimension i.e. 80*50*5 mm by cutter. Then two holes of 8mm and 12mm diameter are made by heavy duty driller to hold the work-piece tightly by the nuts and bolts. After drilled hole in workpiece, Kistler model 9272A piezoelectric drilling dynamometer is to be mounted on T-slot bed with T-type bolts. The above said PMMA strip is settled above the dynamometer by the help of two bolts and washers. With the aid of G-coding program in a CNC drilling machine, the spindle speed and feed are to be inserted as a input parameters in the micro-drilling operation. The output parameters of thrust force and torque are measured simultaneously which were displayed on monitor of amplifier monitor. The machining time is measured with the care of stop watch. After the micro-drilling process, the images of total 10 holes were to be measured by JEOL SEM machine at acceleration voltage of 15KV and magnification of X50.

## 3.1 ANALYSIS OF EXPERIMENT:

Design Of Experiment the branch of applied statistics that deals with planning, conducting, analyzing and interpreting controlled tests to evaluate the factors that control the value of a parameter or group of parameters.[15]an **orthogonal array** is a "table" (array) whose entries come from a fixed finite set of symbols (typically, {1,2,...,*n*}), arranged in such a way that there is an integer *t* so that for every selection of *t* columns of the table, all ordered *t*-tuples of the symbols, formed by taking the entries in each row restricted to these columns, appear the same number of times. The number *t* is called the *strength* of the orthogonal array [16]. Here we use L9 orthogonal array with 3 levels.

## 3.2 GREY RATIONAL ANALYSIS:

Grey Relational analysis are as follows:

- Generating the experimental data tables through Design of Experiment.

- following formula is used to Normalize the output variables:

$$N_{ij} = \frac{(X_{ij})_{max} - X_{ij}}{(X_{ij})_{max} - (X_{ij})_{min}}$$

Here,

- $N_{ij}$= Normalized value after grey relational generation
- $(X_{ij})_{max}$= Maximum value of response parameter
- $(X_{ij})_{min}$= Minimum value of response parameter and
- $X_{ij}$= Value of response in $i_t$ column and $j_{th}$raw of design matrix.

Here i:{1,2,3,4} and j:{1,2,…..,9}

- ❖ Calculation of the grey relation co-efficient.

$$\gamma\ (x_{0j}, X_{ij}) = \frac{\Delta_{min} + \xi\Delta_{max}}{\Delta_{ij} + \xi\Delta_{max}}$$

Here,

- $\Delta_{ij} = |x_{0j} - X_{ij}|$
- $\xi$= Distinguishing coefficient lies between 0 to 1. Here $\xi$ is 0.5.

- ❖ Calculation of Grey Relational Grade which is the average value of grey coeffients.

$$\Gamma = \frac{1}{N} \sum_{k=1}^{n} \gamma\ (x_i(k), x_j(k))$$

Here,

- k= Number of tests.

- ❖ Calculation of total mean grey relational grade.

$$\Gamma_m = \frac{1}{N} \sum_{k=1}^{n} \Gamma(k)$$

- ❖ Calculation of S/N ratio,

$$\text{S/N ratio} = -10 \log \left[ \frac{1}{n} \sum_{k=1}^{n} X^2_{ijk} \right]$$

**………………………..**{for smaller the best}

- ❖ Plot the response graphs by Minitab software to find out the optimized value of different process parameter.

## TABLE NO.2 : LEVELS OF INPUT CONTROL PARAMETER:

| SL/NO | CONTROL PARAMETER | UNIT | LEVEL 1 | LEVEL2 | LEVEL3 |
|---|---|---|---|---|---|
| 1 | FEED RATE | mm/min | 5 | 10 | 15 |
| 2 | SPINDLE SPEED | rpm | 1000 | 1500 | 2000 |
| 3 | DEPTH OF CUT | µm | 30 | 45 | 60 |

## Table No. 3: PROCESS PARAMETER DESIGN:

| RUN ORDER | FEER RATE (mm/min) | SPEED (rpm) | DEPTH OF CUT (µm) |
|---|---|---|---|
| 1 | 5 | 1000 | 30 |
| 2 | 5 | 1500 | 45 |
| 3 | 5 | 2000 | 60 |
| 4 | 10 | 1000 | 45 |
| 5 | 10 | 1500 | 60 |
| 6 | 10 | 2000 | 30 |
| 7 | 15 | 1000 | 60 |
| 8 | 15 | 1500 | 30 |
| 9 | 15 | 2000 | 45 |

## Table No. 4: PERFORMANCE CHARACTERISTIC TABLE:

| RUN ORDER | Fx (N) | Fy (N) | Fz(N) | TORQUE | TIME (min) |
|---|---|---|---|---|---|
| 1 | 1 | 4 | 6 | 0.1 | 4.91 |
| 2 | 1 | 4 | 1 | 0.1 | 4.96 |
| 3 | 1 | 9 | 7 | 0.1 | 4.98 |
| 4 | 0 | 6 | 4 | 0.2 | 2.48 |
| 5 | 1 | 9 | 15 | 0.1 | 2.46 |
| 6 | 0 | 3 | 14 | 0.2 | 2.48 |
| 7 | 3 | 7 | 15 | 0.3 | 1.65 |
| 8 | 0 | 7 | 2 | 0.2 | 1.63 |
| 9 | 0 | 4 | 4 | 0.1 | 1.65 |

### 3.3.1 Normalization:

For smaller the better using: $$N_{ij} = \frac{(X_{ij})_{max} - X_{ij}}{(X_{ij})_{max} - (X_{ij})_{min}}$$

## Table No. 5: GREY RALATIONAL GENERATION:-

| RUN ORDER | Fx | Fy | Fz | TORQUE | TIME |
|---|---|---|---|---|---|
| **IDEAL SEQUENCE** | 1 | 1 | 1 | 1 | 1 |
| 1 | 0.6667 | 0.8333 | 0.6428 | 1 | 0.0208 |
| 2 | 0.6667 | 0.8333 | 1 | 1 | 0.0059 |
| 3 | 0.6667 | 0 | 0.5714 | 1 | 0 |
| 4 | 1 | 0.5 | 0.7857 | 0.5 | 0.7462 |
| 5 | 0.6667 | 0 | 0 | 1 | 0.7522 |
| 6 | 1 | 1 | 0.0714 | 0.5 | 0.7462 |
| 7 | 0 | 0.3333 | 0 | 0 | 0.994 |
| 8 | 1 | 0.3333 | 0.9285 | 0.5 | 1 |
| 9 | 1 | 0.8333 | 0.7857 | 1 | 0.994 |

### 3.3.2 Calculation of Δij:

Using $\Delta_{ij}=|x_{0j} - X_{ij}|$

## Table No. 6: VALUE TABLE FOR $\Delta_{ij}$:-

| RUN ORDER | Fx | Fy | Fz | torque | time |
|---|---|---|---|---|---|
| **IDEAL SEQUENCE** | 1 | 1 | 1 | 1 | 1 |
| 1 | 0.3333 | 0.1667 | 0.3572 | 0 | 0.9792 |
| 2 | 0.3333 | 0.1667 | 0 | 0 | 0.9941 |
| 3 | 0.3333 | 1 | 0.4286 | 0 | 1 |
| 4 | 0 | 0.5 | 0.2143 | 0.5 | 0.2583 |
| 5 | 0.3333 | 1 | 1 | 0 | 0.2478 |
| 6 | 0 | 0 | 0.9286 | 0.5 | 0.2583 |
| 7 | 1 | 0.6667 | 1 | 1 | 0.0006 |
| 8 | 0 | 0.6667 | 0.0715 | 0.5 | 0 |
| 9 | 0 | 0.1667 | 0.2143 | 0 | 0.0006 |

### 3.3.3 Grey relational coefficient:

Using….

$$\gamma\,(x_{0j},X_{ij}) = \frac{\Delta_{min}+\xi\Delta_{max}}{\Delta_{ij}+\xi\Delta_{max}}$$

Here,

- $\Delta_{ij}= |x_{0j} - X_{ij}|$ and
- $\xi$= Distinguishing coefficient varies from 0 to 1. We took $\xi$ as 0.5.

## Table No. 7: GREY RELATIONAL COEFFICIENT:-

| RUN ORDER | Fx | Fy | Fz | TORQUE | TIME |
|---|---|---|---|---|---|
| **IDEAL SEQUENCE** | 1 | 1 | 1 | 1 | 1 |
| 1 | 0.6 | 0.7499 | 0.5832 | 1 | 0.338 |
| 2 | 0.6 | 0.7499 | 1 | 1 | 0.3346 |
| 3 | 0.6 | 0.3333 | 0.5384 | 1 | 0.3333 |
| 4 | 1 | 0.5 | 0.6999 | 0.5 | 0.6593 |
| 5 | 0.6 | 0.3333 | 0.3333 | 1 | 0.6683 |
| 6 | 1 | 1 | 0.3499 | 0.5 | 0.6593 |
| 7 | 0.3333 | 0.4285 | 0.3333 | 0.3333 | 0.9988 |
| 8 | 1 | 0.4285 | 0.8748 | 0.5 | 1 |
| 9 | 1 | 0.7499 | 0.6999 | 1 | 0.9988 |

### 3.3.4 Grey relational grades:

Calculation of Grey Relational Grade, which is nothing but the average value of grey coefficients.

$$\Gamma = \frac{1}{N} \sum_{k=1}^{n} \gamma\,(x_i(k), x_j(k))$$

Here,

- k= Number of tests.

## Table No. 8: GREY RELATIONAL GRADE:

| RUN ORDER | GREY RELATIONAL GRADE |
|---|---|
| 1 | 0.6542 |
| 2 | 0.7369 |
| 3 | 0.561 |
| 4 | 0.6718 |
| 5 | 0.5869 |
| 6 | 0.7018 |
| 7 | 0.4854 |
| 8 | 0.7606 |
| 9 | 0.8897 |

Total Mean of the Grey relational grade =**0.672**

## Table No. 9: DOE FOR GREY BASED RELATIONAL TAGUCHI METHOD TABLE:-

| FEED RATE | SPEED | DEPTH OF CUT | GRADE | SNRA1 | MEAN1 | FITS MEANS1 | FITS SN1 | RESI MEANS1 | RESI SN1 |
|---|---|---|---|---|---|---|---|---|---|
| 5 | 104.71 | 30 | 0.6542 | 3.6857 | 0.6542 | 0.6159 | 4.1523 | 0.0382 | -0.4665 |
| 5 | 157.07 | 45 | 0.7369 | 2.6518 | 0.7369 | 0.7675 | 2.2264 | -0.0306 | 0.4254 |
| 5 | 209.43 | 60 | 0.561 | 5.0207 | 0.561 | 0.5685 | 4.9795 | -0.0075 | 0.0411 |
| 10 | 104.71 | 45 | 0.6718 | 3.4552 | 0.6718 | 0.6793 | 3.4140 | -0.0075 | 0.0411 |
| 10 | 157.07 | 60 | 0.5869 | 4.6287 | 0.5869 | 0.5486 | 5.0952 | 0.0382 | -0.4665 |
| 10 | 209.43 | 30 | 0.7018 | 3.0757 | 0.7018 | 0.7324 | 2.6503 | -0.0306 | 0.4254 |
| 15 | 104.71 | 60 | 0.4854 | 6.2780 | 0.4854 | 0.5160 | 5.8525 | -0.0306 | 0.4254 |
| 15 | 157.07 | 30 | 0.7606 | 2.3768 | 0.7606 | 0.7681 | 2.3357 | -0.0075 | 0.0411 |
| 15 | 209.43 | 45 | 0.8897 | **1.0151** | **0.8897** | 0.8514 | 1.4816 | 0.0382 | -0.4665 |

## TABLE NO. 10: Analysis of Variance for SN ratios

| Source | Degree of freedom | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| **Feed rate** | 2 | 0.5677 | 0.5677 | 0.2838 | 0.47 | 0.679 |
| **Speed** | 2 | 3.6668 | 3.6668 | 1.8334 | 3.05 | 0.247 |
| **Depth of cut** | 2 | 14.1878 | 14.1878 | 7.0939 | 11.81 | 0.078 |
| **Residual error** | 2 | 1.2011 | 1.2011 | 0.6005 | | |
| **Totla** | 8 | 19.6233 | | | | |

## TABLE NO. 11: Analysis of Variance for Means

| Source | Degree of freedom | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| **Feed rate** | 2 | 0.007164 | 0.007164 | 0.00.582 | 0.97 | 0.507 |
| **Speed** | 2 | 0.021724 | 0.021724 | 0.010862 | 2.94 | 0.254 |
| **Depth of cut** | 2 | 0.078776 | 0.078776 | 0.039388 | 10.68 | 0.086 |
| **Residual error** | 2 | 0.007378 | 0.007378 | 0.003689 | | |
| **Totla** | 8 | 0.115043 | | | | |

## TABLE NO. 12: Response Table for Signal to Noise Ratios

Smaller is better

| level | Feed rate | Speed | Depth of cut |
|---|---|---|---|
| 1 | 3.786 | 4.473 | 3.046 |
| 2 | 3.720 | 3.219 | 2.374 |
| 3 | 3.223 | 3.037 | 5.309 |
| delta | 0.563 | 1.436 | 2.935 |
| rank | 3 | 2 | 1 |

## TABLE NO. 13: Response Table for Means

| level | Feed rate | Speed | Depth of cut |
|---|---|---|---|
| 1 | 0.6507 | 0.6038 | 0.7055 |
| 2 | 0.6535 | 0.6948 | 0.7661 |
| 3 | 0.7119 | 0.7175 | 0.5444 |
| delta | 0.0612 | 0.1137 | 0.2217 |
| rank | 3 | 2 | 1 |

# CHAPTER-4
# RESULTS AND DISCUSSIONS

After the completion of the experiment and the theoretical investigation for the optimization of micro milling process parameters we reached to the following results:

1) The optimal condition of the machining parameters are 15mm/min feed rate, 209.43 rpm spindle speed and 45 µm depth of cut.
2) From the signal to noise ratio graph the optimum value occurred at 1.01513.
3) Optimum value for SN ratio occurred for feed rate in 3rd level, for spindle speed in 3$^{rd}$ level and depth of cut in 2$^{nd}$ level.
4) Total mean grey relational grade is 0.672
5) Depth of cut is **additional vital** than the spindle speed and Feed rate as it has the minimum value of P i.e. 0.077 in the ANOVA table of means.
6) The points on the residual vs. fitted value graph do not produce any pattern therefore it has zero error.
7) SN ratio at optimum value is increased by 0.466568 i.e 45.96% whereas mean value is decreased by 0.0382333 i.e. 4.29%.
8) From the response table it is clear that Depth of cut is the most substantial characteristics as its rank is 1
9) Our investigation is unto the mark as we get the normally distributed graph.
10) Maximum width of the slot as seen by the SEM machine is 1.05mm and the total mean average width of the slot is 1.009mm.
11) From the SEM images we have seen that the width of the slots are nearly same as that of the cutter diameter but there are some burr formation takes place.

## GRAPHS:

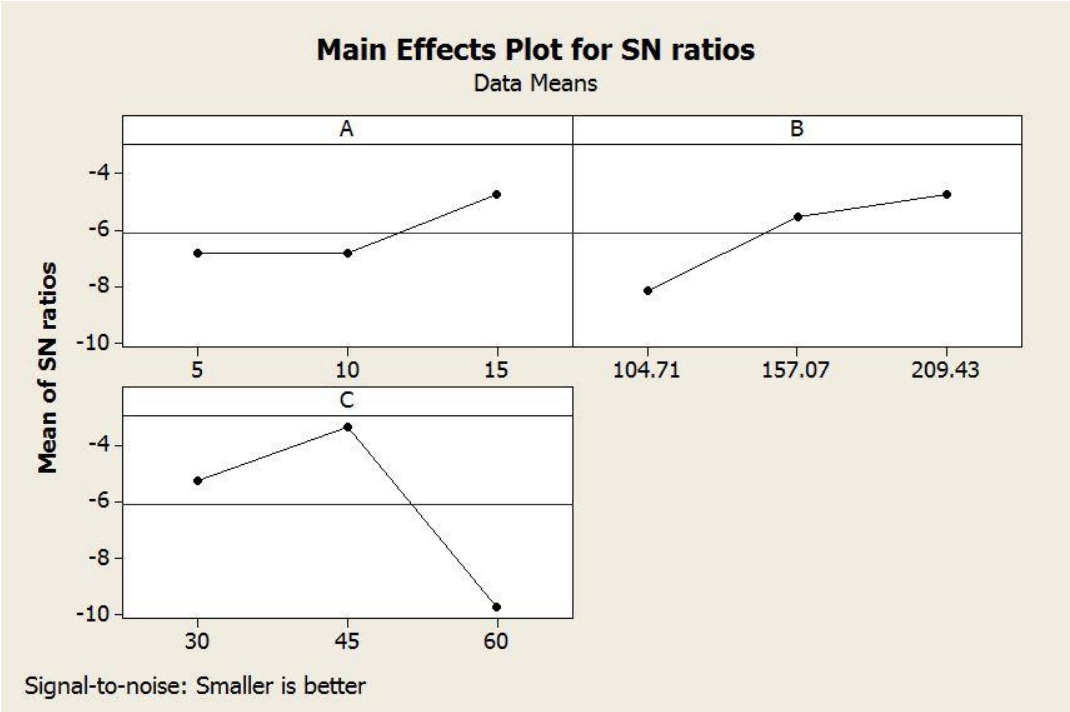


**Figure No. 3 (Graph no. 1): Main Effect Plot for SN Ratio**

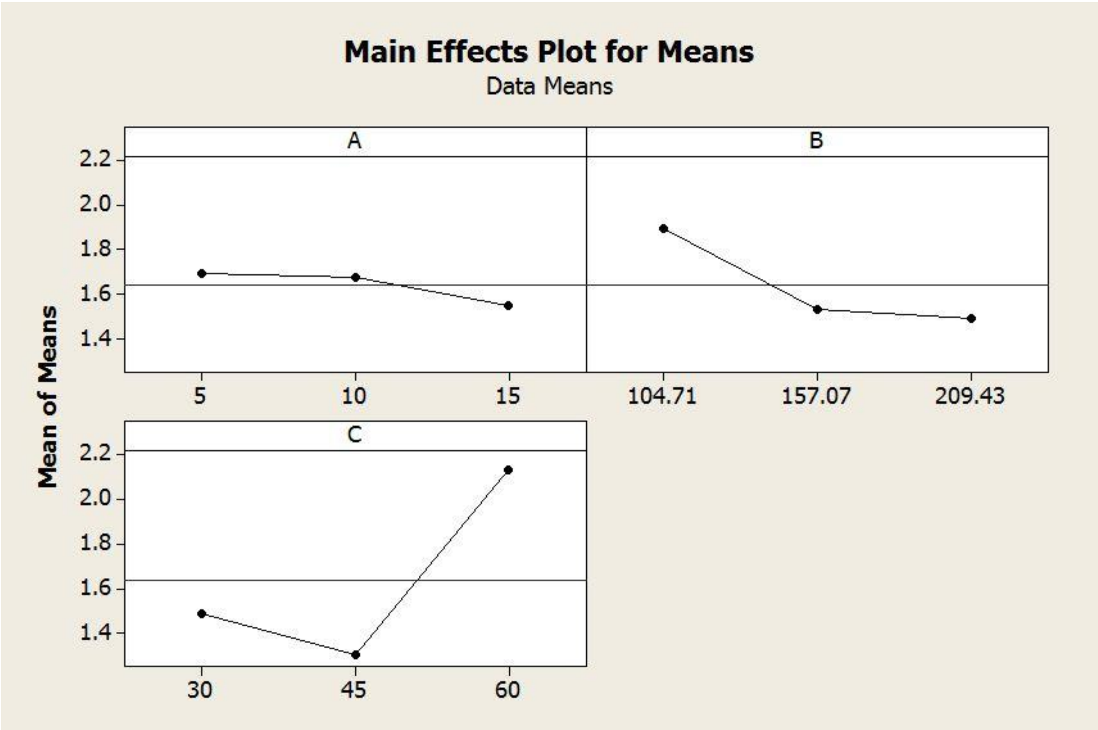


**Figure No. 4 (Graph no. 2): Main Effect Plot for Means**

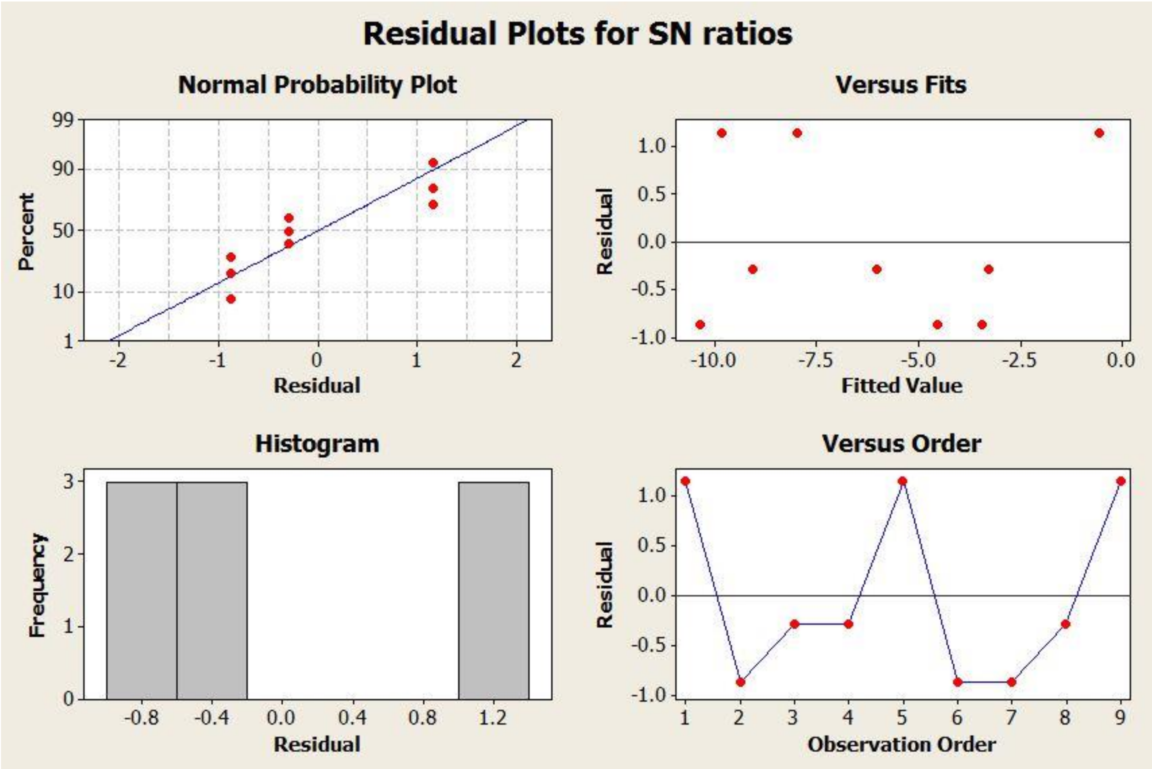


**Figure No. 5 (Graph No. 3): Residual Plot for SIGNAL TO NOISE Ratio**

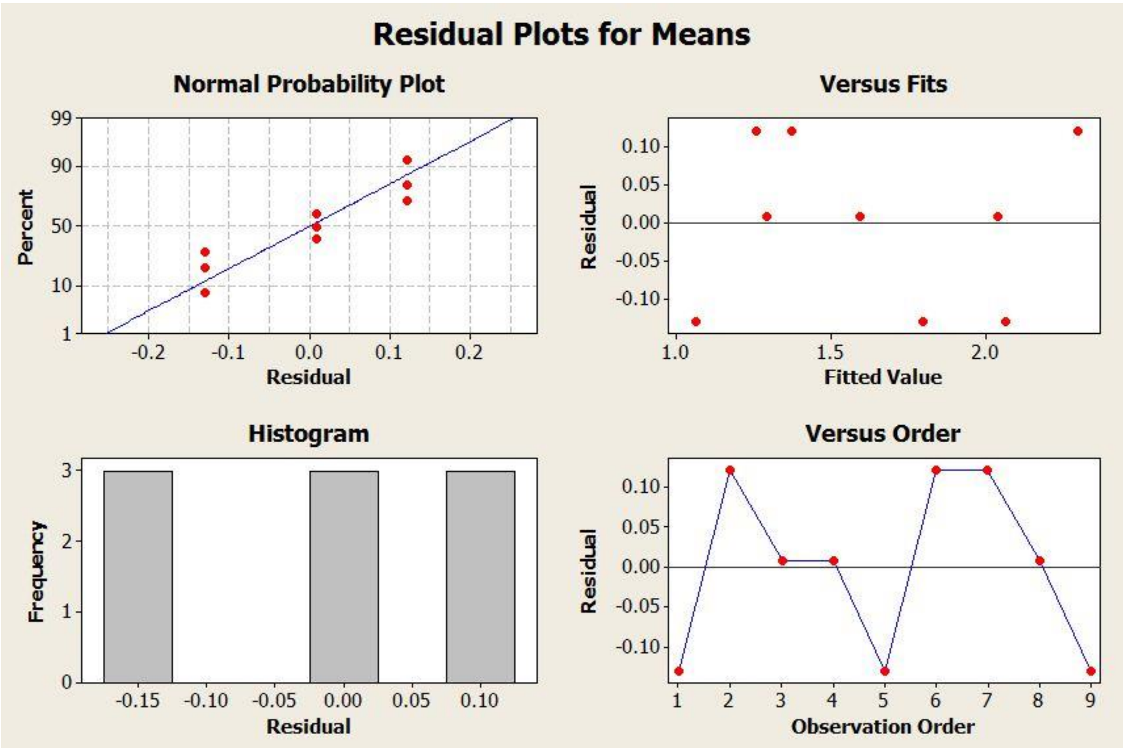


**Figure No. 6 (Graph No. 4): Residual Plot forMeans**

**TABLE NO. 14: SEM RESULTS:**

| RUN NO | SAMPLE 1(µm) | SAMPLE 2(µm) | SAMPLE 3(µm) | SAMPLE 4(µm) | SAMPLE 5(µm) | MEAN (µm) |
|---|---|---|---|---|---|---|
| 1 | 972 | 1000 | 992 | 996 | 1000 | 992 |
| 2 | 1030 | 1020 | 1020 | 1020 | 1010 | 1020 |
| 3 | 1010 | 1040 | 1040 | 1000 | 1000 | 1010 |
| 4 | 996 | 1020 | 980 | 1020 | 1040 | 1011 |
| 5 | 1040 | 1050 | 1020 | 1040 | 1030 | 1036 |
| 6 | 996 | 996 | 1010 | 996 | 984 | 996 |
| 7 | 1010 | 1000 | 1040 | 1010 | 1020 | 1016 |
| 8 | 1030 | 1000 | 1020 | 1020 | 996 | 1012 |
| 9 | 968 | 1010 | 992 | 996 | 1000 | 993 |

TOTAL AVERAGE SLOT WIDTH IS: 1.009mm.

## 3.4 IMAGES FROM SCANNING ELECTRON MICROSCOPE:-

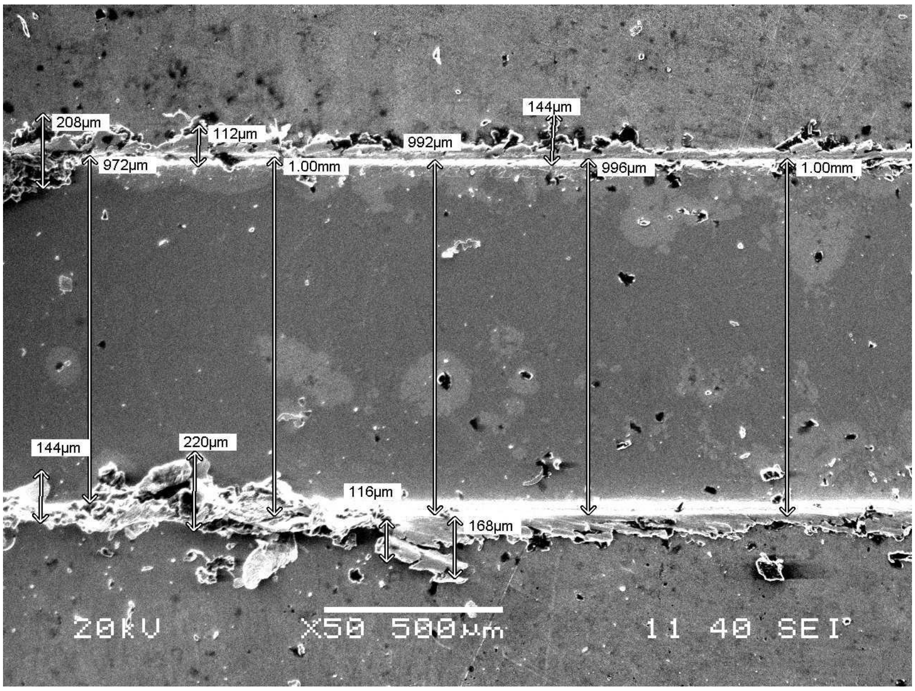


**Figure No. 7: SEM IMAGE FOR Slot No. 1**

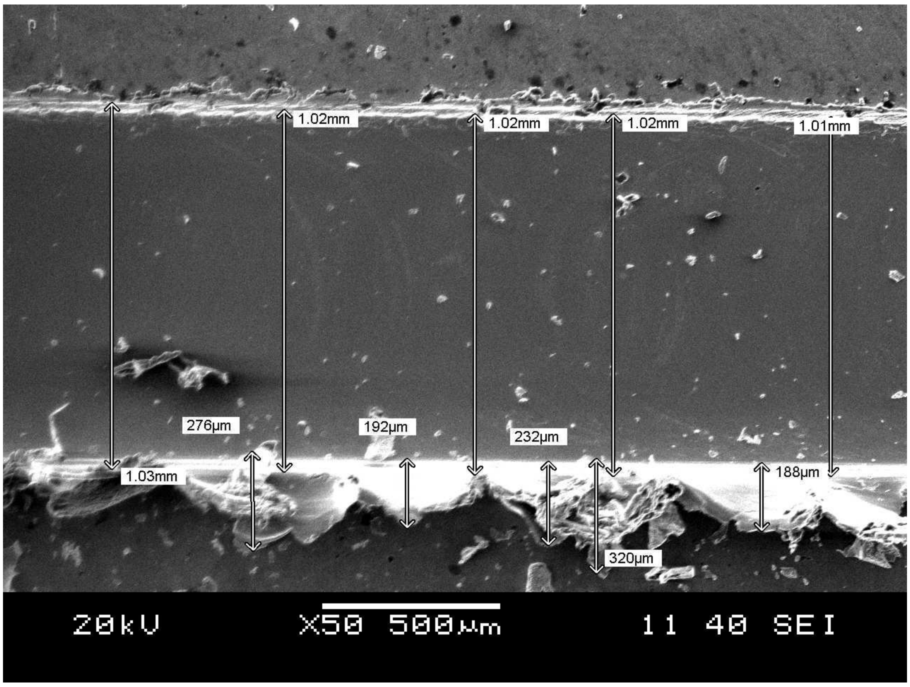


**Figure No. 8: SEM IMAGE FOR Slot No. 2**

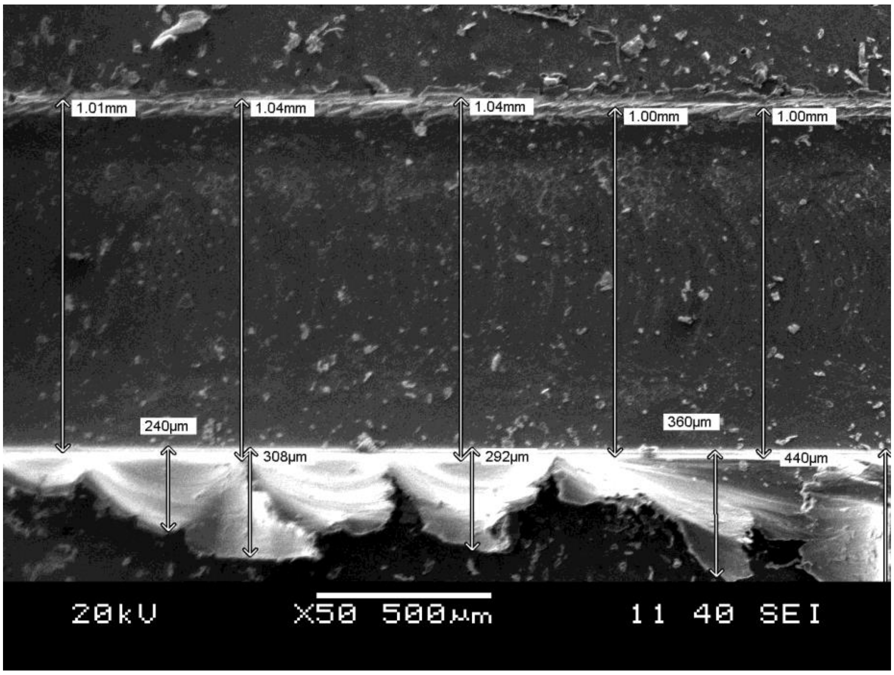


**Figure No. 9: SEM IMAGE FOR Slot No. 3**

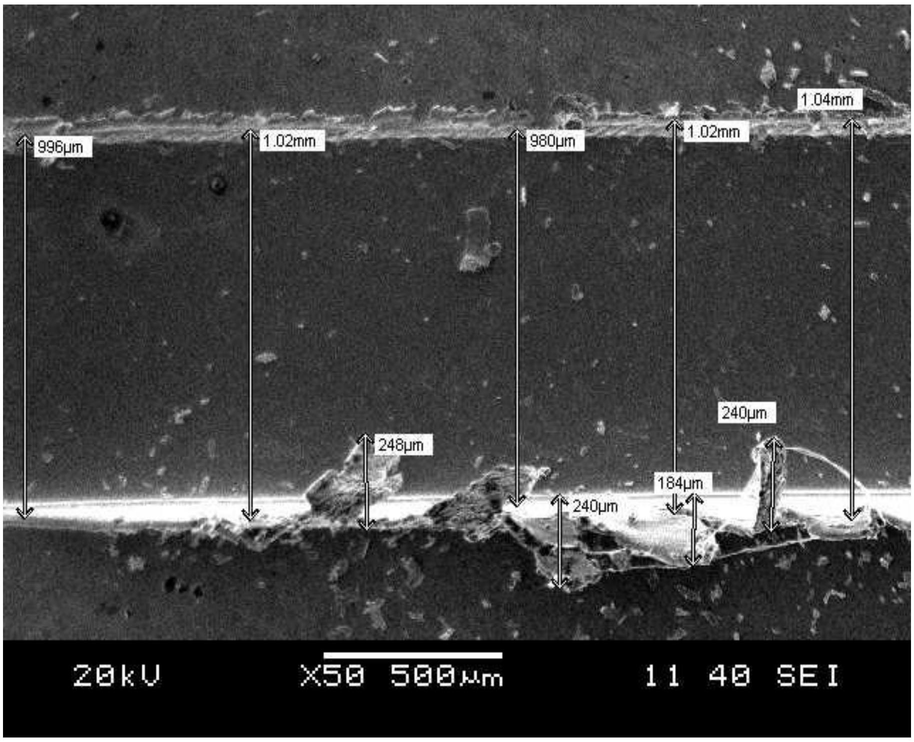


**Figure No. 10: SEM IMAGE FOR Slot No. 4**

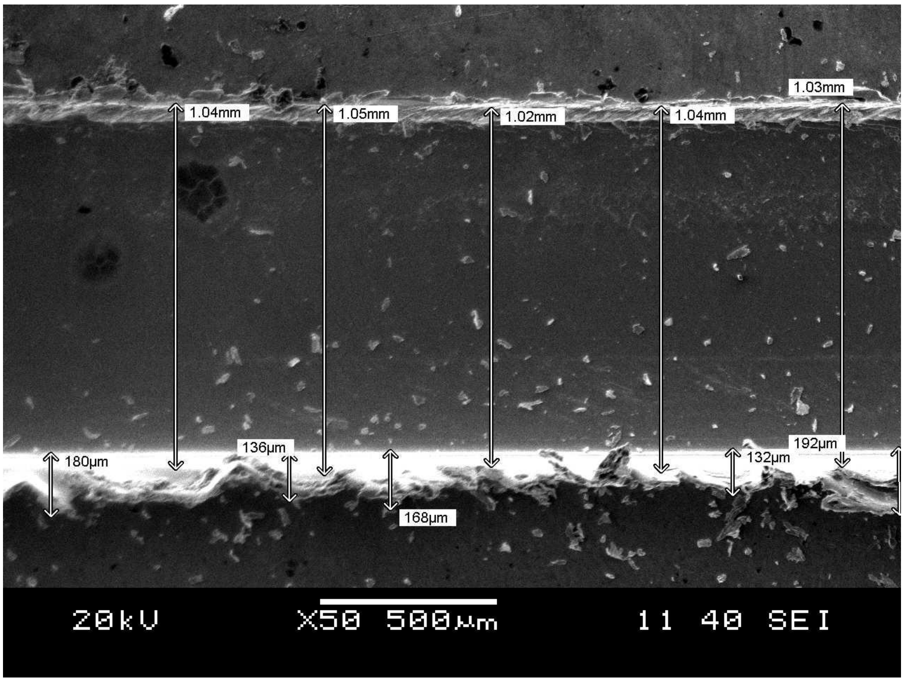


**Figure No. 11: SEM IMAGE FOR Slot No. 5**

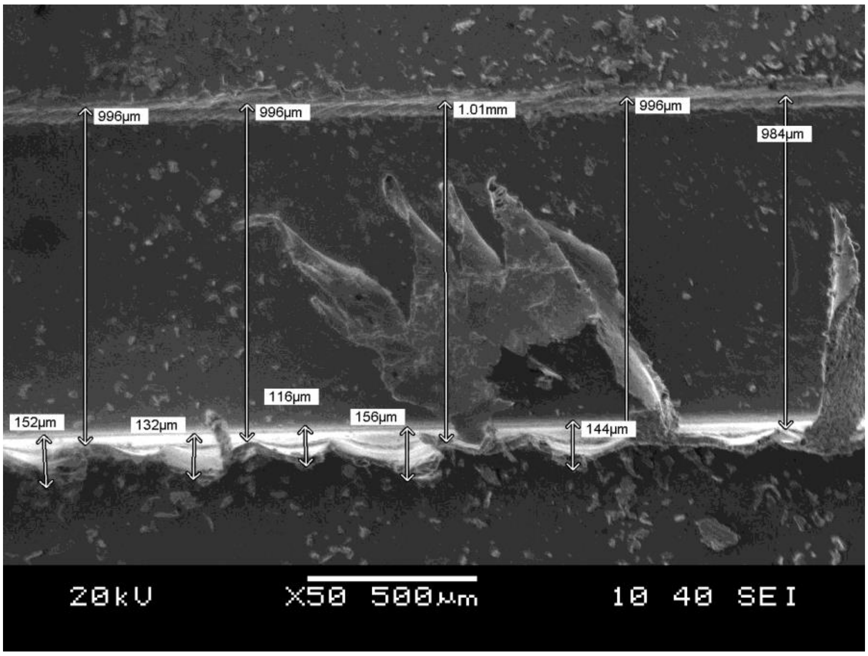


**Figure No. 12: SEM IMAGE FOR Slot No. 6**

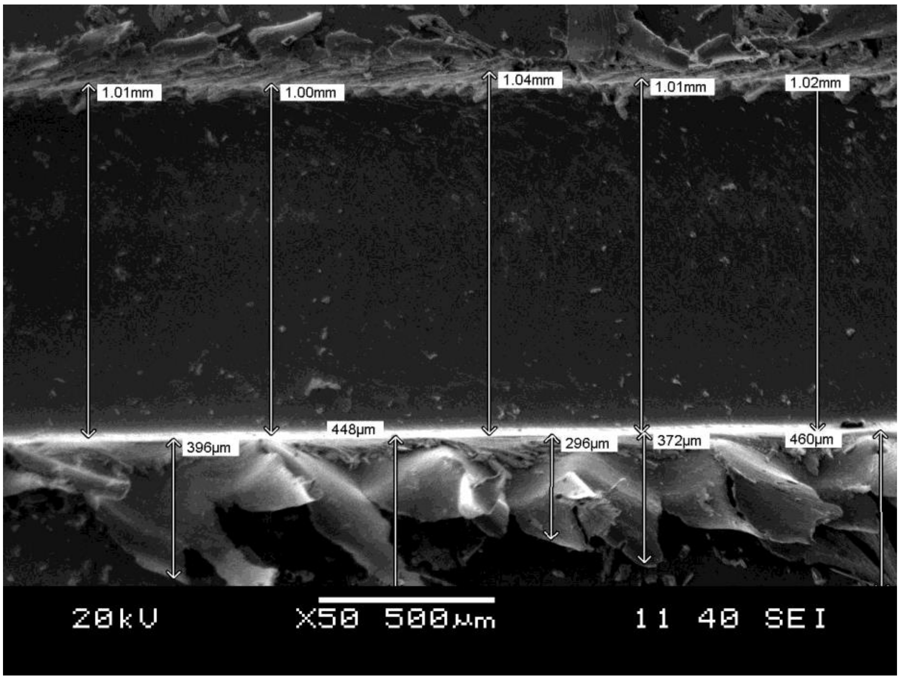


**Figure No. 13: SEM IMAGE FOR Slot No. 7**

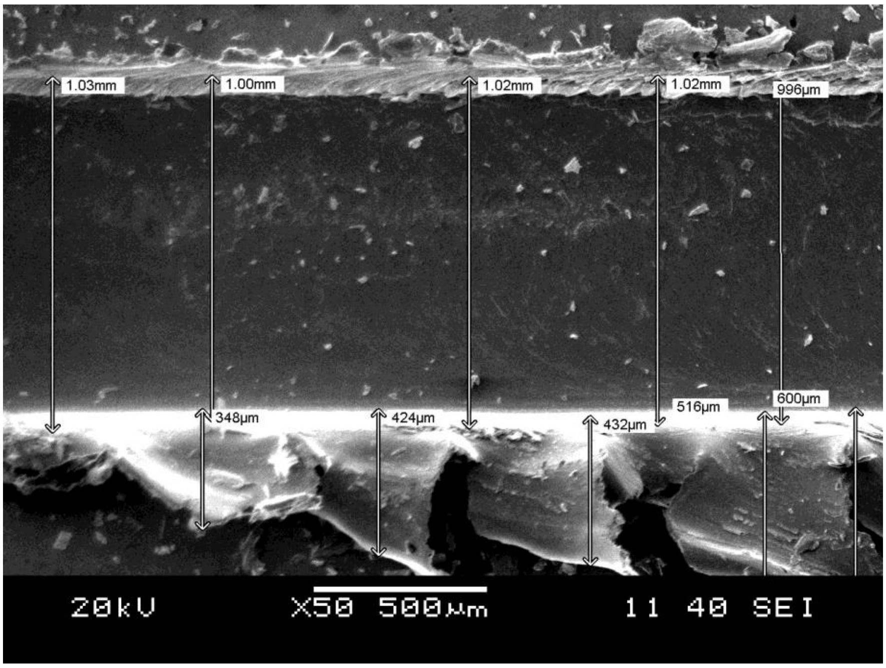


**Figure No. 14: SEM IMAGE FOR Slot No. 8**

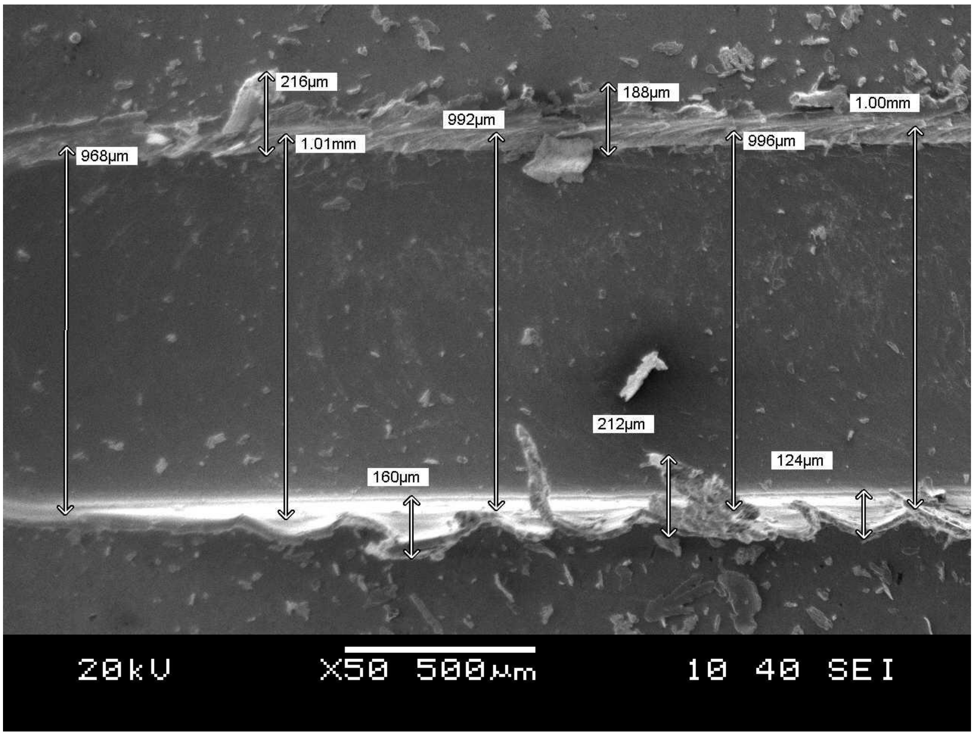


**Figure No. 15: SEM IMAGE FOR Slot No. 9**

# CHAPTER-5

# CONCLUSION:

Our investigation of micro milling of Inconel aerospace alloy with High Speed Steel tool of 1mm diameter is conducted successfully on the CNC machine. Our main objective was to determine the optimal value of the process parameter commonly used in the micro milling process which are Feed Rate, Spindle Speed and Depth of cut so as to reduce the output parameter such as cutting force, cutting time and cutting torque. And we conclude our investigation as follows:

1) As the parameter depth of cut increases the output variables force, time and torque decreases. Hence to get low value of cutting force, cutting time and torque it require high depth of cut value.
2) While in case of other machining parameter like feed rate and spindle speed, low value of these parameters are preferable
3) The optimal condition of the machining parameters are 15mm/min feed rate, 209.43 rpm spindle speed and 45 µm depth of cut.

# CHAPTER-6

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